

TRAFFIC SIGNAL CONTROLLER INTERFACE

FINAL REPORT
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Traffic Section

Prepared by

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TABLE OF CONTENTS

ABSTRACT	1
INTRODUCTION- SIGNALIZED INTERSECTION TRAFFIC CONTROL	2
BACKGROUND- FULLY AND SEMI ACTUATED SIGNALIZED CONTROL	3
METHODS- FORCE OFFS AND PERMISSIVE PERIODS	5
CALCULATING FORCE OFF TIMES AND PERMISSIVE PERIODS.....	6
Force Off Calculations	7
Permissive Period Calculations	8
Beginning of Permissive Periods.....	10
Duration of Permissive Periods.....	10
REFERENCES	13

ABSTRACT

Designing signalized control requires engineers to perform a complex set of tasks. Effectively moving vehicles through an intersection with signalized control involves hardware capable of reliable service. Beyond this, the hardware must also be flexible to accommodate fluctuating volumes of vehicles or demand. In the past, signal controller hardware was mechanical. Mechanical controllers could only display fixed intervals of green service for each approach within a fixed period of time or cycle length. Along an arterial of several intersections, these controllers could provide coordinated control by setting the service times according to progressing traffic. Mechanically coordinated control would only be effective as long as the mechanisms didn't drift with time. Mechanical timekeepers lost coordination because they couldn't be perfectly synchronized.

Newer technology provides options to change the lengths of approach service depending upon demand. Furthermore, contemporary controllers provide ability to achieve perfect synchronization along an arterial with multiple intersections. These advanced features are possible through computer processors within the controllers. Input, such as detection of vehicles, can be processed for accurate, appropriate output or signal control.

Since traffic controller hardware now uses computer processors, they must be programmed with software or decision conditions to control traffic. These decision conditions are focused upon demand, which can change with time of day or day of week. Designing signal timings is normally accomplished using optimization software. Not all design parameters are available through software tools, so an engineer must make calculations manually. This project explains how to calculate two important parameters used in coordinated – actuated signal control and to develop a tool to calculate them directly. Force Off times are necessary for proper coordination and Permissive Periods provide intervals when non-coordinated movements at an intersection can be served according to approach demand.

INTRODUCTION- SIGNALIZED INTERSECTION TRAFFIC CONTROL

Traffic control at intersections can be accomplished in many ways. The most simple is with stop signs on intersection approach streets with less volume. Depending on certain criteria, such as volume and approach speed, a four way stop may be installed. When volumes are very large and a four way stop is creating unfavorable delay (and/or other circumstances) a signal may be used to control traffic flow. With a signal set on fixed time for each movement or phase, all lanes of all approaches to an intersection are guaranteed green time.

A fixed time signal controller must have certain parameters entered into it. These parameters are a cycle length, phase green times, yellow intervals, and red times for each phase. Once initiated, all phases, whether there are vehicles present or not, will be served with green lights. Obviously, the drawback is allocation of green time to users that don't exist. Semi actuated and fully actuated controlled intersections are programmed to check for demand before a phase is served. If there isn't a vehicle waiting to be served, the light will not display green for that movement if the controller is programmed to behave accordingly.

Fully actuated and semi actuated control require advanced input into controllers for proper operation. Beyond normal timings for fixed time intersection control, a controller at an intersection designed for actuated control will need to have force off times for each actuated phase. Furthermore, the controller also requires permissive periods. These parameters allow for smart intersection control that serves the needs of motorists. The purpose of this document is to explain the terms Force Off and Permissive Period then present methodology for calculating these parameters.

BACKGROUND- FULLY AND SEMI ACTUATED SIGNALIZED CONTROL

The idea behind actuated control is to serve phases where there is demand. At semi-actuated controlled intersections, an arterial is given absolute priority until a call comes from a side street. Cycle lengths cannot be infinite for many types of controllers, so there must be a length of time entered into the controller for a cycle. If a minimum green time for the side street phases of 0 is entered, it may be possible to have many cycles of continuous green on the main street until a call comes from one of the side street approaches. Once a side street phase is served the controller checks for a minimum green time and stays green until that time is reached. If there is still more demand on the minor street, the green is extended until it reaches a maximum time. Maximum time for a phase is another parameter entered into the controller for each movement. During normal operation, the force off and maximum times will coincide in the cycle.

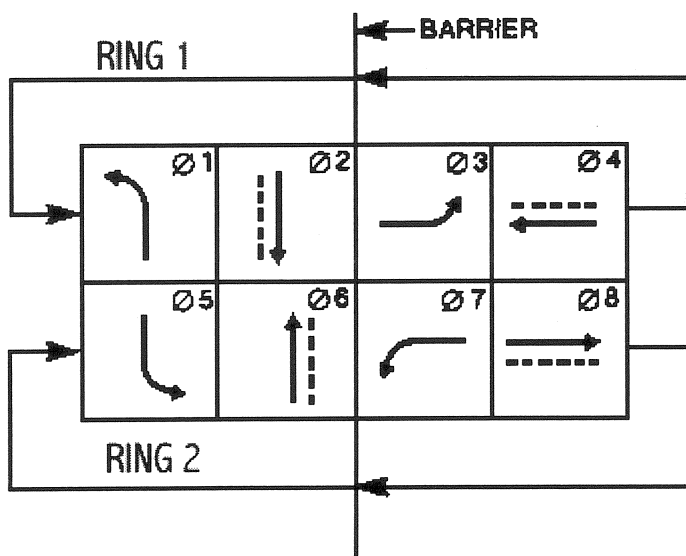
Fully actuated intersections are similarly controlled, but according to demand on every approach instead of one or two. Any indications of priority at fully actuated intersections would be the maximum and minimum times allocated to phases. More time will be allocated to the priority phases. Another indication is whether or not the actuated intersections along an arterial are coordinated to allow a continuous platoon of vehicles to proceed through several intersections with least delay. Phases at a coordinated actuated intersection will require parameters that will turn off a phase, regardless of demand, when the platoon is approaching. This parameter is called the phase Force Off Time and will be applied to each phase at a coordinated actuated intersection. Some agencies refer to preemption control as a force off to non-preempted phases.¹ Preemption is a different kind of force off and is calculated differently.

Another necessary parameter for actuated coordinated signal control is the Permissive Period. The Permissive Period is the time within a phase when a call for service on another approach can be served with minimum green before a Force Off occurs. For example, in a NEMA dual ring phase configuration, phases 2 and 6 are the coordinated

phases while phases 1 and 5 are the left turns which can be associated with the through movements of 6 and 2 respectively. The coordinated phases will not ever have permissive periods because that would defeat the purpose of coordination. Figure 1 displays the NEMA/ITD phase movement assignment. ITD has swapped the rings on the left side of the barrier to create a more uniform system within the State. On the 1,2,5,6 side of the barrier, phases 2,6 and 1,5 will normally be exclusively paired. Other possibilities exist for phases on the second side of the barrier. Phases 3 and 7 can be green and a call for service occurs on phase 4. If the call comes within the Permissive Period of phase 3, phases 7 and 4 will be served. If the demand on 4 comes after the Permissive Period, there isn't enough time to serve phase 4 minimum green and therefore the phase isn't served until the coordinated phase is over or until the next cycle. Different combinations can be seen at T-Intersections or other reduced phase intersections.

Some agencies call the end of the coordinated phase the “yield in the cycle”². A Yield Point in a coordinated phase is the beginning of the Permissive Period when enough time remains for the calling phase to have minimum green before it will be forced off. Force Off Times and Permissive Periods or Yield Points are only relevant in actuated, coordinated signalized traffic control.

Figure 1. NEMA/ITD Dual Ring Phases



METHODS- FORCE OFFS AND PERMISSIVE PERIODS

Several methods exist for calculating Force Offs. Choosing a method depends upon the phase sequence design, split, and priority of progression. In general, application of a method to determine Force Off Times will include determination of Permissive Periods. Sometimes, it is necessary to compute the permissive periods prior to calculating the force off times. Controllers capable of coordinated actuated signal control will be capable of at least manual entry of phase force off times and permissive periods with yield points. Some will have an option to calculate and input them automatically using the cycle length, phase split, and offset as input.

Traffic Control Technologies NEMA LMD 8000 controllers offer automatic calculation of Force Off Times and Permissive Periods according to three methods.³ The first option is to extend a fixed 5 second permissive to all phases from the coordinated phase force off. A second method is more complicated and allows the coordinated phase to remain green if there are no calls to the next phase. It also prevents the subsequent phase, normally occurring after the skipped phase, from starting too early. Furthermore, opportunity is provided to late arrivals on the phase normally following the coordinated phase. A third method is to start all permissive periods at the force off point of the coordinated phase. Each permissive ends before the phase force off to allow clearance of coordinated phase and minimum green time.

Floating Force Off Times are another option that utilizes traffic responsive algorithms like Volume-Density to change cycle lengths and phase timings according to fluctuating demand. Volume-Density control isn't normally available for coordinated intersection control since a bandwidth for an arterial is dependent upon related cycle lengths from intersection to intersection. The most commonly used Force Off / Permissive method is similar to the third method available for the TCT LMD 8000 controllers.

CALCULATING FORCE OFF TIMES AND PERMISSIVE PERIODS

A fixed time signal design is an appropriate starting point since most agencies use optimization software packages to generate signal phase fixed green times. It is arguable to use these times as either the maximum or minimum green times. For this example, green times are that which has been allocated to the phase from optimization software. From the way they are used in the following example, they will be considered maximum green times. The major argument is optimized times dissipate normal queues according to data entered into software. That would mean they are minimum green times and a factor should be used to multiply minimum timings to accommodate larger queues.

Minimum green times for phases will typically be the greater of either conflicting pedestrian times or a policy assigned minimum green time. Assumed in this example is a policy 5-second minimum green time for all phases. Total time allocated to a phase is optimized green plus yellow plus red and is called the phase split. In other words, phase split times include the yellow plus red for the phase. Red times aren't added into the split unless the phase termination occurs before the barrier is crossed. Conceptually, the end of the phase split without the clearance and red interval, is the phase force off.

Assume that optimization software produced the following timing design:

<i>Phase</i>	<i>Green Time (sec)</i>	<i>Yellow (sec)</i>	<i>All Red Interval (sec)</i>	<i>Split (sec)</i>
2/6	35	3	3	41
3/7	20	4	-	24
4/8	25	3	3	31
1/5	25	4	-	29
	Cycle →			125

An example of calculating the phase Force Offs and Permissive Periods will be demonstrated for a simple NEMA signal design in a coordinated arterial. This first example is patterned after a presentation given in TRAF NETSIM manual.⁴

Force Off Calculations

Before an example can make sense, it is necessary to put Force Off calculation in concept. Each Force Off relationship presented here will be preceded by a conceptual explanation. Assuming that phase 2,6 is the coordinated movement between intersections, the Force Off for 2,6 is the maximum green for that phase, plus clearance or yellow and all red time. Although not always necessary, it is a good idea to calculate the Force Off times in order of service after the coordinated phase and assuming that the cycle ends when the green for the coordinated phase ends. The end of the coordinated phase is also the zero point in the cycle. If the zero point in the cycle is shifted, the calculations will be shifted by the same duration. Phase 3,7 follows the coordinated movements and then phases 4,8 and 1,5 are served in this signal design.

Generally, phase 3,7 follows 2, 6 which is on the other side of the barrier. This is logical since the permissive movements of phases 1 and 5 will come before 2 and 6 are served in the dual ring scheme. The force off time in the cycle for phase 3,7 is equal to the phase 2,6 clearance + phase 3,7 split - phase 3,7 clearance. Time = 0 is just before phase 2,6 clearance, therefore that clearance time must be added to the green time for phase 3,7 which is the split time - clearance. Phase 4,8 follows phase 3,7.

$$\begin{aligned}\text{Force off time for } \Phi 3/7 &= \Phi 2/6 \text{ clearance} + \Phi 3/7 \text{ split} - \Phi 3/7 \text{ clearance} \\ &= 3 + 3 + 24 - 4 = 26 \text{ seconds}\end{aligned}$$

Force off for phase 4,8 is calculated by adding times from the zero point to the end of green time allocated for phase 4,8. Phase 2,6 clearance starts at 0 and is followed by the 3,7 split, then the 4,8 split. Since the splits include the clearance and red interval, it is required to subtract the clearance of phase 4,8 for the proper force off time. The clearance

for split 3,7 is not subtracted because the time value will change during that period pushing the force off time ahead.

$$\begin{aligned}\text{Force Off time for } \Phi 4/8 &= \Phi 2/6 \text{ clearance} + \Phi 3/7 \text{ split} + \Phi 4/8 \text{ split} - \Phi 4/8 \text{ clearance} \\ &= 3 + 3 + 24 + 31 - 3 + 3 = 55 \text{ seconds}\end{aligned}$$

Phase 1,5 occurs after the force off for phase 4,8. The same pattern of adding up the intervals before the phase service is followed.

$$\begin{aligned}\text{Force Off time for } \Phi 1/5 &= \Phi 2/6 \text{ clearance} + \Phi 3/7 \text{ split} + \Phi 4/8 \text{ split} + \Phi 1/5 \text{ split} - \Phi 1/5 \\ &\quad \text{clearance} \\ &= 3 + 3 + 24 + 31 + 29 - 4 = 86 \text{ seconds}\end{aligned}$$

Force Off calculations for lead / lag designs are like this example, but reflect the lead or lag in phases within the Force Off time for the phase. It is important to note that in a NEMA dual ring scheme, one has to omit the red interval for phases that occur in sequence with phases on the same side of the barrier. Although there will be a red light displayed for phases 1,5 and 3,7 it will not contribute to the overall cycle length or to the split for those phases. This is why clearance times in this numeric example for phases 1,5 and 3,7 (4 seconds) are different than clearance times for phases 2,6 and 4,8 (6 seconds).

Permissive Period Calculations

For the most part, different methods for calculating phase Force Off times is like the example above. This isn't necessarily true for different methods of calculating Permissive Periods. Design choices have to be made based upon demand patterns before a method will apply.

The Permissive Period is the time in each non-coordinated phase when other non-coordinated phases can be served according to demand. Demand on approaches cannot always be predicted on a microscopic level, but the Permissive Periods attempt to allow

some flexibility in the phase sequences so that unexpected arrivals can be efficiently served.

In our example, as well as most dual ring timing designs, there are three non-coordinated phases in each cycle: $\Phi 3/7$, $\Phi 4/8$, and $\Phi 1/5$. This provides a possibility for three Permissive Periods. During the first Permissive Period, one of the other non-coordinated (NC) phases can be served. For another NC phase to be served in a Permissive Period, these specific conditions must be met:

- 1) Demand on one of those phases exists,
- 2) There is no demand on the NC phase being served, and
- 3) There is enough time left to serve the minimum green before the Force Off is reached.

Opportunity to serve only two NC phases exists during the second Permissive Period. The third Permissive Period can only serve demand on one phase if there isn't demand on the phase currently being served. Some designs will provide opportunities to all NC phases like this, while others will only offer permissive service to one NC phase for each Permissive Period.

Before calculations can be made, it is necessary to decide on a method or general approach for the Permissive Periods. The methods are almost limitless and little published material exists to validate or recommend any method over another. Generally, agencies will implement different methods until one is found to satisfactorily serve traffic demands. Some designs simply allocate the first 5 seconds of each non-coordinated phase as the Permissive Period. Other designs attempt to maximize the Permissive Period for each non-coordinated phase, while yet another design may skip a phase in a cycle if demand isn't detected within a specified Permissive Period.

The following example calculations will show how to find the maximum Permissive Periods for each NC phase. It follows the method given in reference 4, the TRAF/NETSIM manual. It is the most commonly used method for finding Permissive Periods and is close to the method used to calculate the timings automatically with

controllers and software used to program NEMA controllers. Most often the automatic algorithms within controllers is proprietary and not accessible to practitioners or researchers.

Different agencies will adopt a particular method and use it because it is how they have always done it. The Idaho Transportation Department typically applies a lead / lag method for phases 1 and 5.

Beginning of Permissive Periods

Knowing that each Permissive Period needs to be as long as possible helps to know when each period begins.

Permissive Period 1 will begin immediately after the coordinated phase green terminates which is before the yellow + all red is displayed prior to crossing the barrier. This location in the cycle is called the yield point and it corresponds to the zero point in the cycle. Beginning points for the other two permissive periods are just as simple.

Permissive Period 2 begins at the force off point of the first NC phase in the cycle.

Permissive Period 3 begins at the force off point of the last NC phase in the cycle.

Duration of Permissive Periods is more complicated, but trying to maximize them will help.

Duration of Permissive Periods

Minimum green time for non-actuated phases plays an important role in the duration of Permissive Periods. A minimum green for the calling phase is the time out of the current phase (after it has received minimum green and before it is forced off) needed to serve the calling phase. Most optimization software will not calculate minimum green times

because it may be policy for an area or simply determined by pedestrian times. In this example, a minimum green time of 5 seconds is applied to all NC phases. Ends of Permissive Periods indicate when there isn't enough time left to serve demand on another phase. The duration of Permissive Period 1 is phase 3,7 Force Off time minus time in the 3,7 phase that cannot be used for any other phase, minus additional time from the yield point.

$$\begin{aligned} \text{Duration of Permissive Period 1} &= \text{Force Off } \Phi_{3/7} - \Phi_{3/7} \text{ min. green} - \Phi_{2/6} \text{ clearance} \\ &= 26 - 5 - (3 + 3) = 15 \text{ seconds} \end{aligned}$$

Permissive Period 2 is calculated by subtracting the time in the next phase that can't be used for permissive service from the absolute value of the difference of phase 3/7 force off and phase 4/8 phase force off. Force off for $\Phi_{3/7}$ is the beginning of the second permissive period.

$$\begin{aligned} \text{Duration of Permissive Period 2} &= |\text{Force Off } \Phi_{4/8} - \text{Force Off } \Phi_{3/7}| - \text{min. green } \Phi_{4/8} - \\ &\quad \Phi_{3/7} \text{ clearance.} \\ &= 55 - 26 - 5 - 4 = 20 \text{ seconds} \end{aligned}$$

End point of Permissive Period 2 in cycle is $26 + 20 = 46$ seconds.

Permissive Period 3 is calculated like Permissive Period 2, but using timings from the next phase.

$$\begin{aligned} \text{Duration of Permissive Period 3} &= |\text{Force Off } \Phi_{1/5} - \text{Force Off } \Phi_{4/8}| - \text{min. green } \Phi_{1/5} \\ &\quad - \Phi_{4/8} \text{ clearance.} \\ &= 86 - 55 - 5 - (3 + 3) = 20 \text{ seconds} \end{aligned}$$

End point of Permissive Period 3 in cycle is $55 + 20 = 75$ seconds.

It should be noted that once a NC phase is serviced through activation during a Permissive Period, the cycle returns to normal operation and deactivates remaining Permissive Periods. Reactivation of Permissive Periods occurs when the cycle returns to the yield point after serving the coordinated phase.

Figure 2 shows the cycle with Force Off Points.

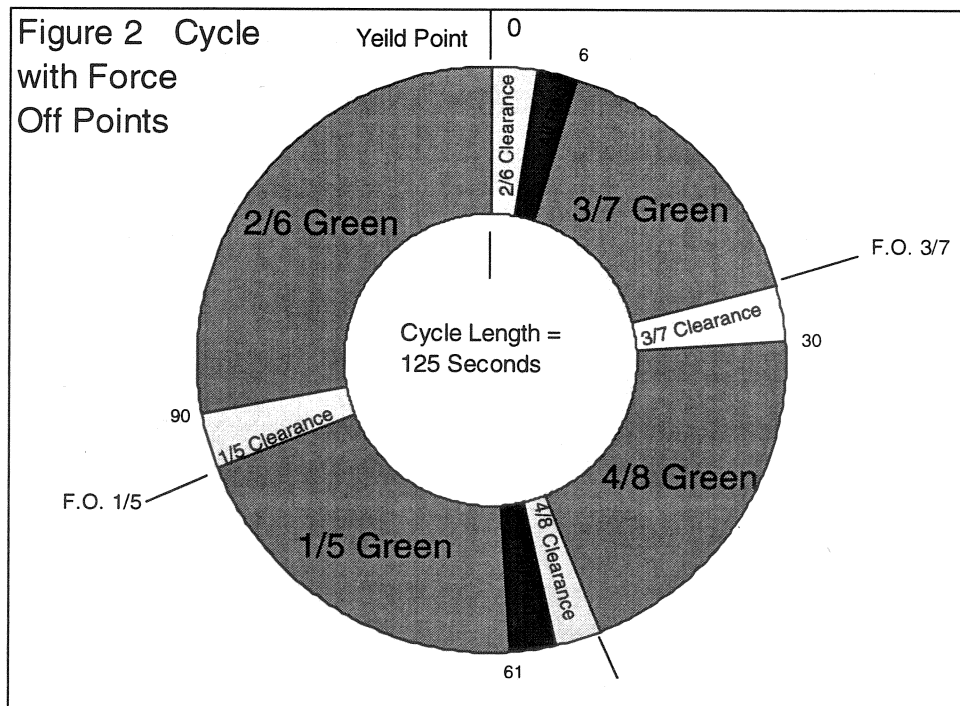
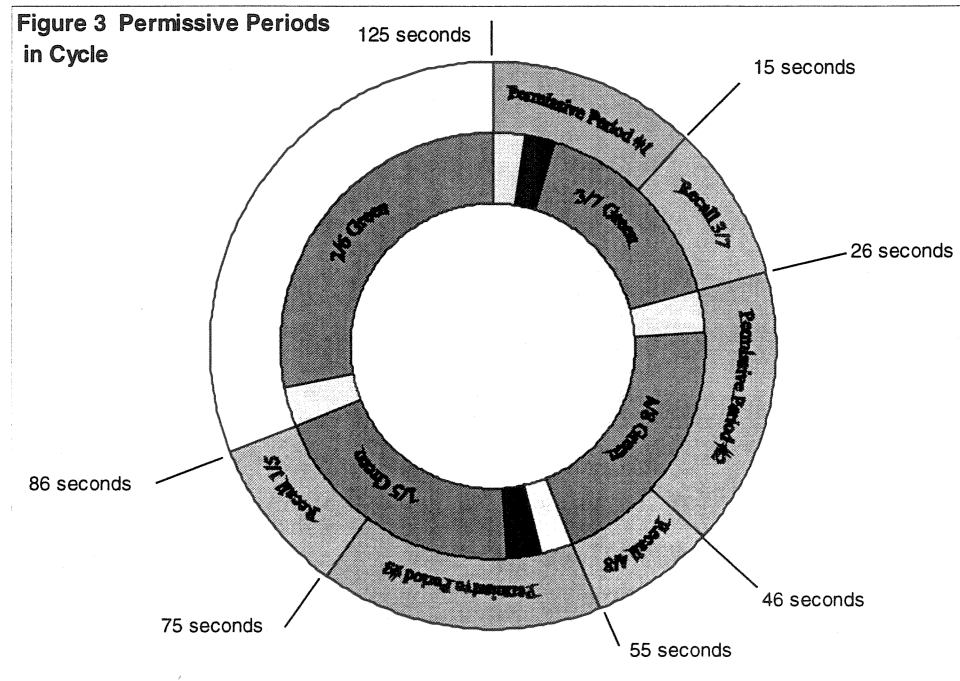


Figure 3 displays the cycle with Permissive Periods.



References

¹ Technical Data Bulletin 147T, Traffic Control Technologies LMD 8000 Actuated Controller Unit. July 1993. Page G-4.

² Traffic Control Systems Handbook, US Department of Transportation and Federal Highway Administration. February 1996. Page 8-7.

³ Technical Data Bulletin 147T, Traffic Control Technologies LMD 8000 Actuated Controller Unit. July 1993. Page 3B21.

⁴ Actuated Controllers in TRAF: Record Types 43-48. Vigen Corporation. Document No. TD0001. Rev. 1.01. August 1996. Page 12.

